Evolution of the microstructural surface characteristics during annealing

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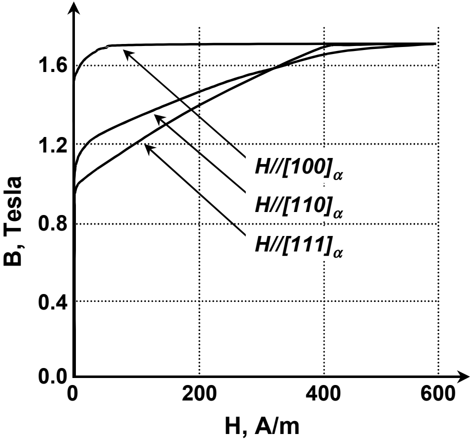
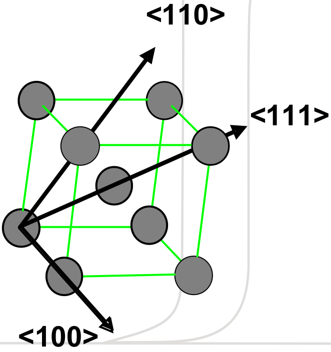
Outline

Magnetic Anisotropy of bcc iron lattice



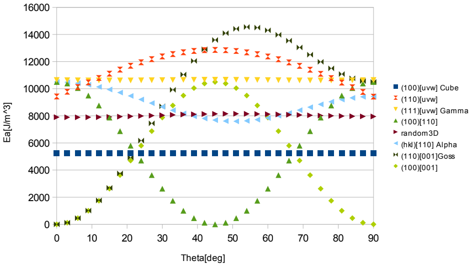


Texture in electrical steel

Magnetic properties of electrical steels depend on crystallographic texture due the magnetic anisotropy of iron crystal.

$$E_A = K_1\left(\alpha_1^2\alpha_2^2 + \alpha_2^2\alpha_3^2 + \alpha_1^2\alpha_3^2\right)$$

for 1^{st} order approximation



Routes to obtain cube fibre

Still not possible to obtain the desired cube fibre in a industrial process, but several routes have been applied at lab scale:

- Cross-rolling
- Directional solidification
- Surface annealing treatment
- ...

Surface annealing treatment

- Hashimoto *et al.* investigated the $\alpha \rightarrow \gamma \rightarrow \alpha$ phase transformation texture at the surface of an ultra low carbon cold rolled steel sheet and reported that a <100> // ND texture was formed rather than the usual <111> //ND texture.
- Aspeden *et al.* reported that an annealing treatment for an ultra low carbon steel in the austenitic temperature region followed by a slow cooling resulted in a stronger <100>//ND texture.
- In all of these works it was assumed that the resulting surface texture was produced due to the lowest metal/vapour interface energy in the {001} fibre.

$\alpha \rightarrow \gamma \rightarrow \alpha$ transformations

- $\alpha \rightarrow \gamma \rightarrow \alpha$ seems to be need the in surface annealing treatment.
- Young-Kurdjumov-Sachs (YKS) is the most commonly cited orientation relationship model.
- $\{111\}_\gamma \parallel \{011\}_\alpha$ and $[111]_\gamma \parallel [011]_\alpha \rightarrow 24 \times 90°\langle 112 \rangle$
- In double transformation each component will result in $576\ (24 \times 24)$ product orientations.

Outline

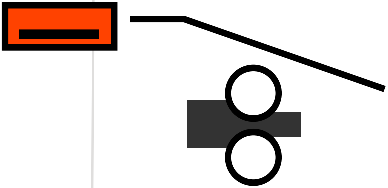
Chemical composition

- Ultra low carbon steel with additions of manganese and aluminium.

Sample Name	C [wt%]	Mn [wt%]	Si [wt%]	Al [wt%]
A	0.002	1.28	0.22	0.29

Pre-processing

Pre-processing



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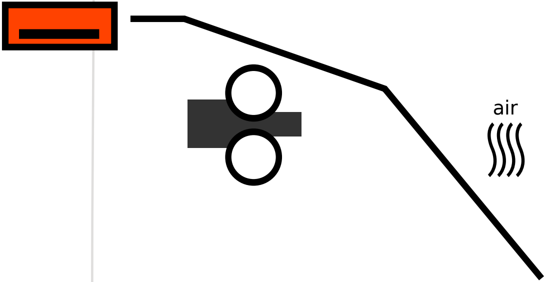

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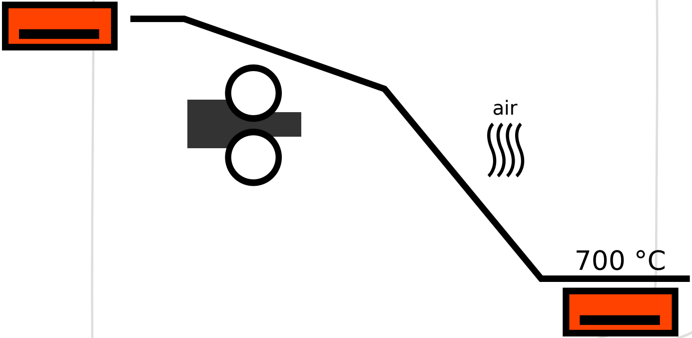

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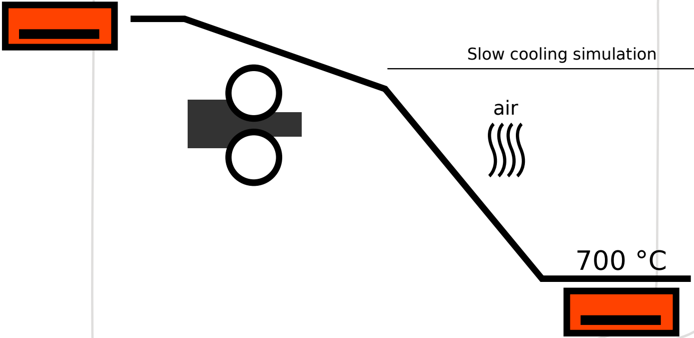
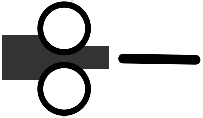
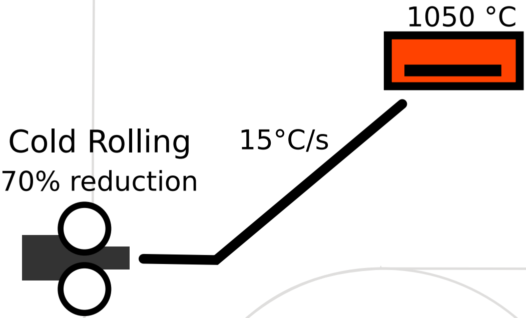


Thermal treatment

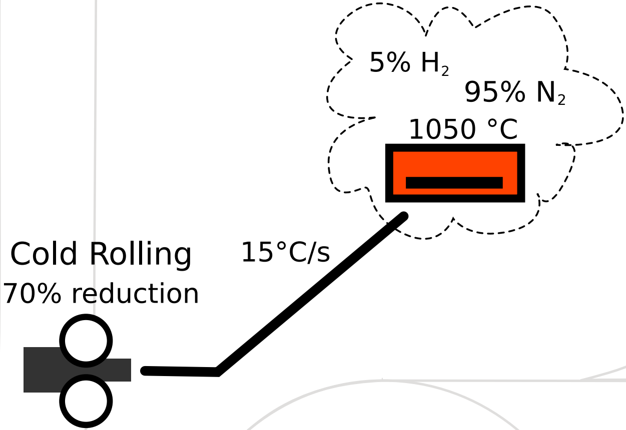
Cold Rolling
70% reduction



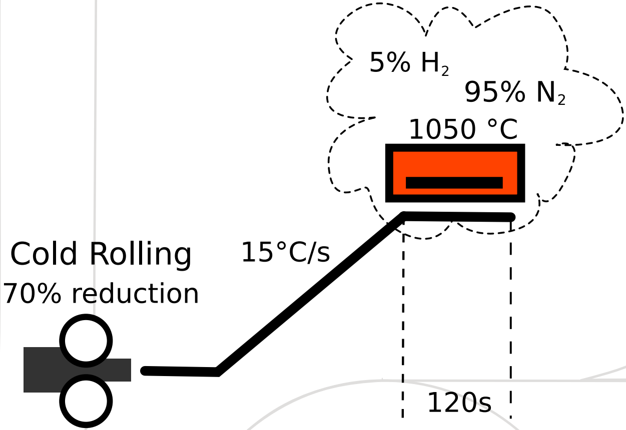
Thermal treatment



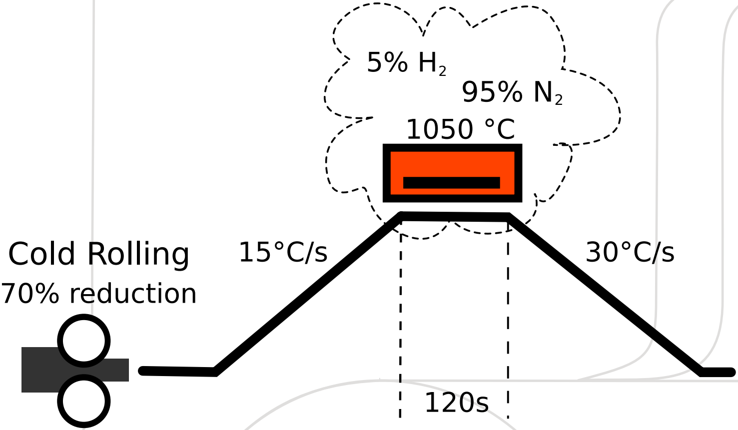
Thermal treatment



Thermal treatment

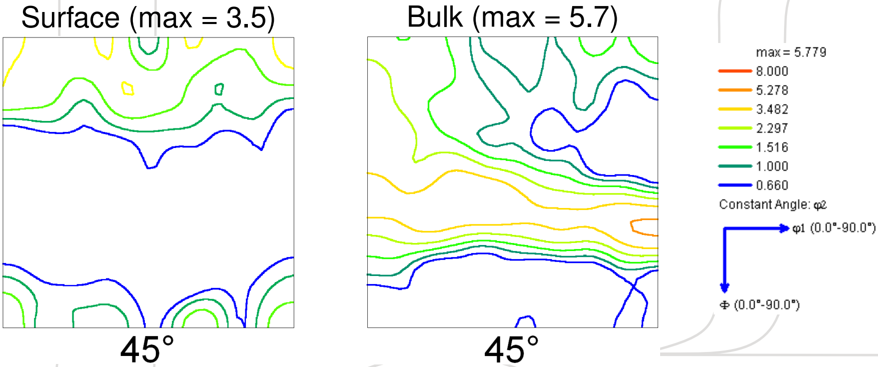


Thermal treatment

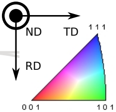


Outline

Texture


Surface (max = 3.5)
45°
Bulk (max = 5.7)
45°
max = 5.779
8.000
5.278
3.482
2.297
1.516
1.000
0.660
Constant Angle: φ2
φ1 (0.0°-90.0°)
Φ (0.0°-90.0°)

IPF map on ND surface section



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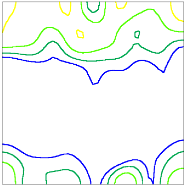
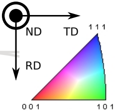
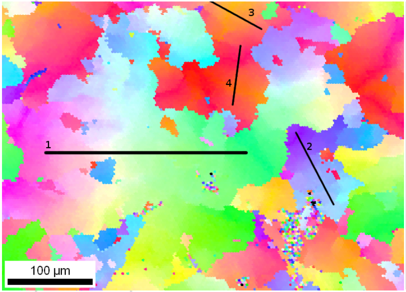
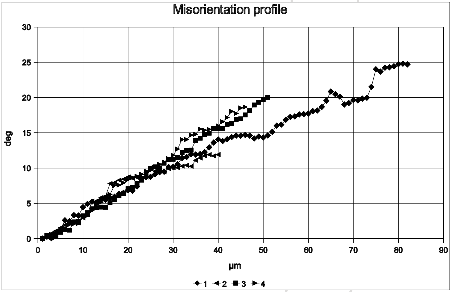


45°

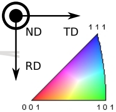


Gradient everywhere





Flower morphology



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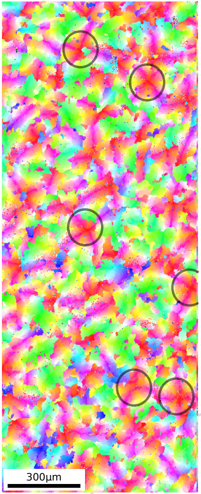

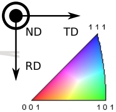

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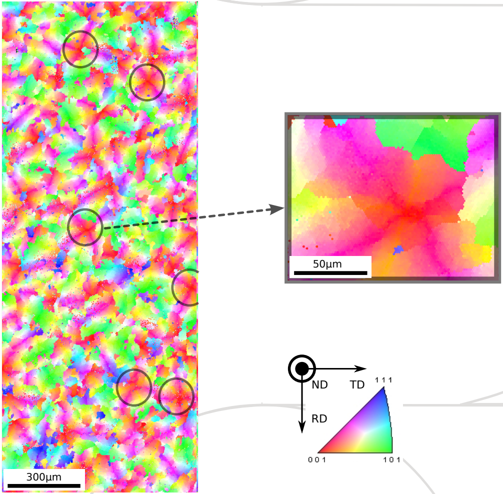
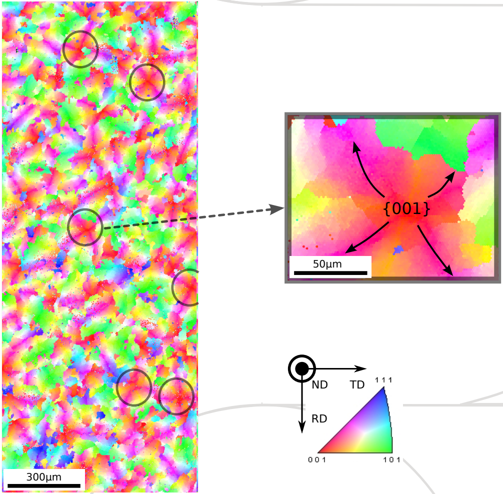
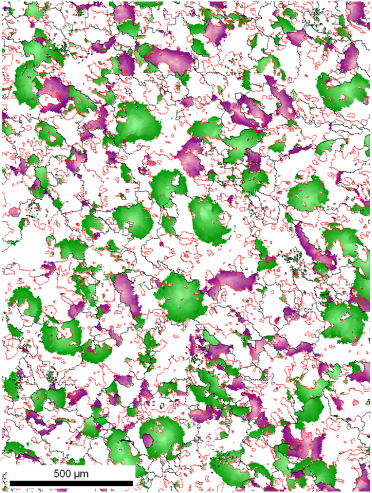


Flower morphology



Cube and ⟨110⟩ ∥ *ND* areas



	Direction	Min	Max	Total Fraction	Partition Fraction
green	<0 0 1>||[0 0 1]	0°	15°	0.203	0.203
purple	<0 1 1>||[0 0 1]	0°	10°	0.094	0.094

Iron (Alpha)

[001]

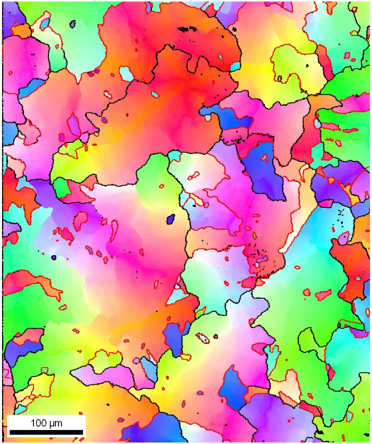
Boundaries: Rotation Angle

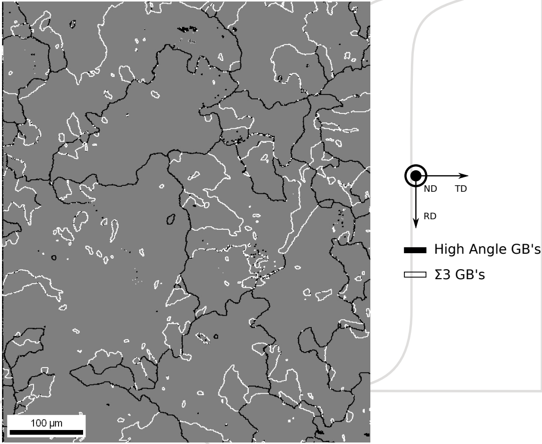
	Min	Max	Fraction	Number	Length
black	15°	180°	0.983	93638	18.92 cm

Boundaries: CSL

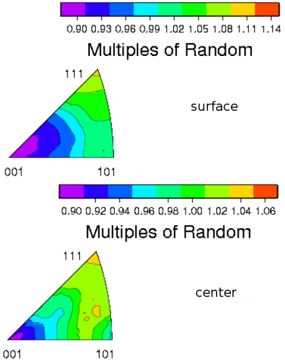
	Sigma	Tolerance	Fraction	Volume	MDF Value	Number	Length
red	3	8.66	0.387	0.0176	22.01	53305	10.7715 cm
	summary	-	0.387	0.0176	22.01		

Σ3 grain boundaries





Grain Boundary Character Distribution (GBCD) [1] [2]

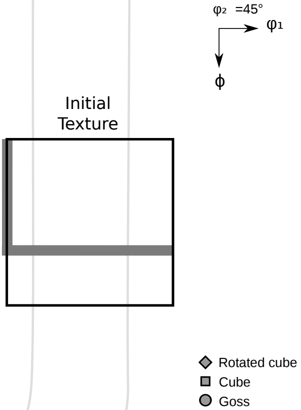


	Surface	Bulk
$\Sigma3$	40.5%	10.3%
Coherent $\Sigma3$	0.89%	0.90%

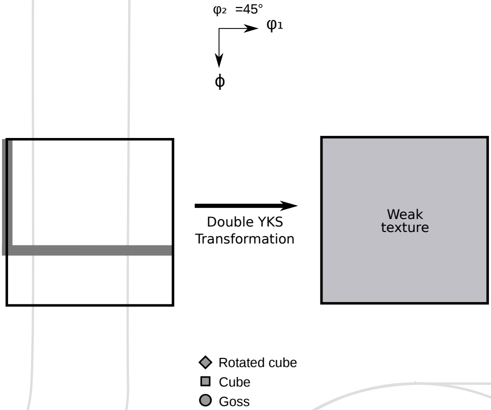
[1] Calculated with Rohrer's software. G. Rohrer *et al*, Zeitschrift fur Metallkunde (2004)

[2] The input data was not achieved, as it requires at least 50,000 segments for typical cubic symmetry situations.

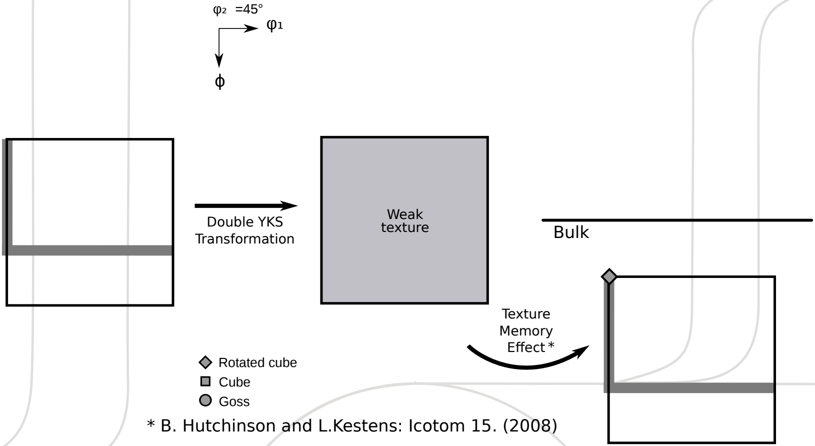
Texture evolution



Texture evolution



Texture evolution



* B. Hutchinson and L.Kestens: Icotom 15. (2008)

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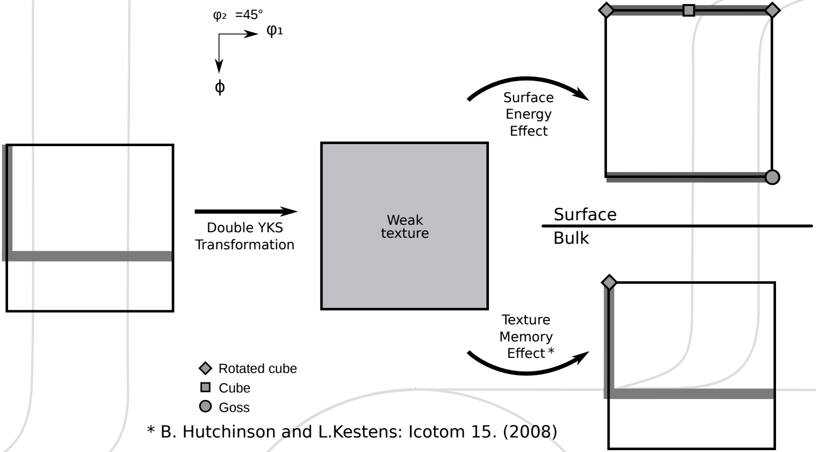

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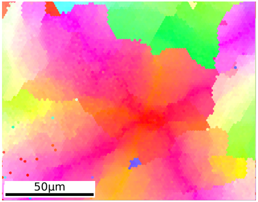
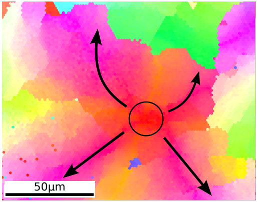
Orientation shifting

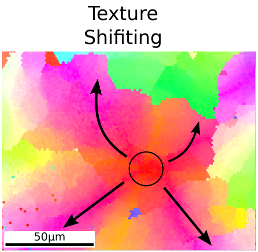


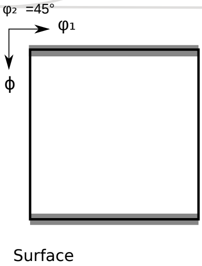
Orientation shifting

Texture
Shifiting



Orientation shifting





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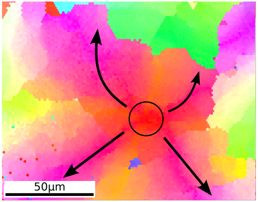
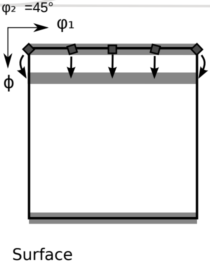
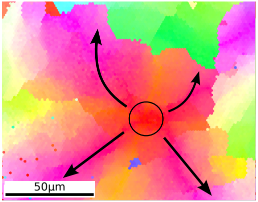
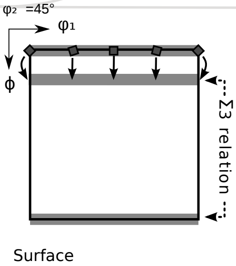




Orientation shifting

Texture Shifiting





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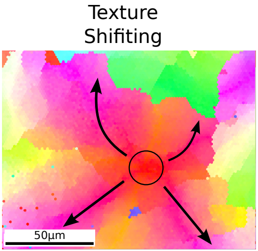

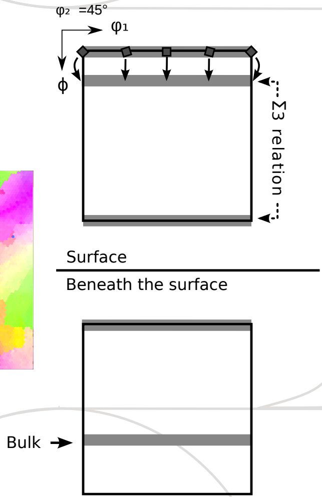

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Texture
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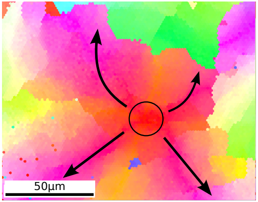

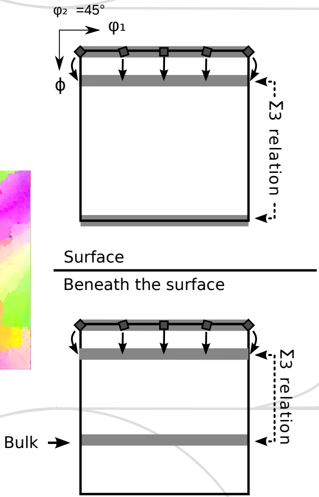

Outline

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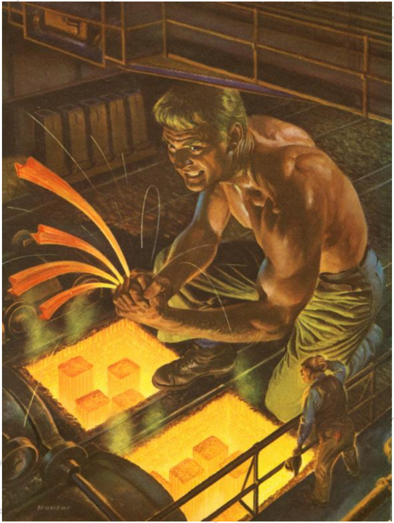
Mystery

How do cube grains know that 5-10° misorientation will make them met at Σ3 boundaries with {110}//ND grains ???

Thank for your attention !!!



"Joe Magarac, was a man made of steel. He was born in an iron ore mine and raised in a furnace... He made railroad rails by squeezing molten steel between his fingers."

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